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NICD SPACE BATTERY TEST DATA ANALYSIS PROJECT PHASE 2

by

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FIRST QUARTERLY REPORT

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Prepared for

GODDARD SPACE FLIGHT CENTER

Greenbelt, Maryland

CONTRACT NAS 5-10203

MAUCHLY SYSTEMS, INC.

MONTGOMERYVILLE INDUSTRIAL CENTER

Montgomeryville, Pa.

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APPROVED: J. H. Waite

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GREENBELT, MARYLAND

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ABSTRACT

NiCd cell-failure-characteristic data, for cells made by four battery-cell manufacturers, was computer examined by a technique of cryptology or cryptanalysis.

This is a new use of cryptanalytic technique which was previously only used by security agencies to 'break' ciphers and codes. The Crane failure characteristic reports were assumed to contain hidden information or information not readily extractable by manual analysis. This assumption proved correct when the data was treated like a code or cipher. Application of cryptanalytic technique extrapolated information which identified specific cell failure mechanisms accountable to individual battery-cell manufacturers. This procedure, referred to in this report as "TRI-GRAM Failure Characteristic Technique", is applicable to any coded data.

Cell failure characteristic/cycling environmental parameter analysis will be performed to correlate failure mechanisms with single and combined environmental effects.

INTRODUCTION

This is the first quarterly report, covering the period from January 1, 1967 to April 30, 1967, for contract number NAS 5-10203, Phase 2, in accordance with Proposal No. 17-1216 BATT entitled "Techniques in Space Battery Test Data Analysis, Reduction and Correlation".

The following objectives are set forth as goals to be attained by this study:

1. Develop and demonstrate methods for prediction of cell failure as a function of failure characteristics and operating constraints.

2. Develop and demonstrate new techniques for extraction and presentation of information from a large volume of space battery test data.

3. Develop improved methods for the collection and handling of the Crane data.

4. Develop mathematical models related to battery tests as practicable and useful to the battery user.

5. Instruct Crane in the functioning and use of computer programs and techniques developed under this contract.

Since about January, 1963, the Secondary Battery Section of the Quality Evaluation Department at NAD Crane, Indiana has been cycling, monitoring, and collecting data on sealed nickel-cadmium space battery cells. Part of these data consists of failed-cell post-mortem autopsy reports, in detailed English, performed on every cell after failure.

INTRODUCTION (Cont'd)

After close examination of these autopsy reports, covering several hundred cells, it was considered that valuable information, particularly information on failure-mechanisms, was hidden or occulted in the mass of data. Manual analysis of the cell-autopsy data was impossible because of the large mass of varied failure characteristics contained therein.

A technique used in cryptology, for the purpose of 'breaking' or 'cracking' secret ciphers and codes, was applied to the mass of failure characteristic data; treating the data itself as a secret code containing a message of sorts. The use of cryptology and cryptanalytic technique as applied to industrial or failure data is believed to be new and novel. This technique has heretofore been in the domain of secret intelligence agencies and secret agents. Modern cryptography makes full use of mathematics and electronics to gather information from seemingly meaningless signals or data.

The failure characteristic data, reported by Crane, were converted into a coded structure of twenty-one different failure characteristics represented by the letters A through U. Table A shows the code legend. These coded failure characteristics were entered onto punch cards; each card, representing one battery pack, with both pack and manufacturer identification. A maximum card field of up to seven characters was allowed to represent the coded failure characteristic information for each identified cell. This convention permitted coded information for a pack of up to ten cells to be contained in one punch card.

A computer was programmed, the program being an application of cryptology or cryptanalysis, to examine the coded data and to construct tables showing the frequency of failure by one characteristic jointly with each of of the other failure characteristics. The resultant tables were called

INTRODUCTION (Cont'd)

"BIGRAM" tables because they indicate the combinatorial frequency of any two coded failure characteristics. Information regarding cell failure by specific "BIGRAMS" was found to apply to individual cell manufacturers. More information concerning "BIGRAM" tables can be found in the Appendix of this report, page 38.

Certain success was achieved by the use of "BIGRAM" tables but it was considered that much more specific failure mechanism information could be gained by measuring the joint frequency of any three coded failure characteristics. A "TRI-GRAM" frequency program was then the logical evolution of the "BIGRAM" technique.

The "TRI-GRAM" technique is so called because it indicates the combinatorial frequency for any three coded failure characteristics with each other. It is also a cryptanalytic process.

The "TRI-GRAM" technique has enabled us to pinpoint specific failure mechanisms assignable to individual battery cell manufacturers who can then evaluate possible design/material imperfections in their product. This manufacturer/failure mechanism relationship is dealt with at length in the discussion section and appendix of this report.

The major purpose in the use of this cryptanalytic technique is that it enables the correlation of observed 'N'-gram frequencies with probabilistic frequencies based on mono-gram occurrences. 'N'-gram probability distribution tables are constructed from ('N'-1) gram distribution tables. When the observed 'N'-gram occurrence differs from the probabilistic 'N'-gram table, the observed 'N'-gram of coded failure characteristics is highly suspect of being a failure mechanism.

INTRODUCTION (Cont'd)

Observed mono-gram frequency distributions are the basis for "BIGRAM" probability tables; observed "BIGRAM" distributions are the basis for "Tri-Gram" probability tables, etc. 'N'-gram distributions are constructed until 'N' is too high to permit sufficient frequency for observation. For additional 'Bigram' information see page 38.

Analogous to this procedure is the relative frequency of usage for letters in the English language. In a typical sample of English, for example, about 13 percent of the letters will be E's, 9 percent T's, 8 percent O's, and 2 percent P's. Although these frequencies will vary from sample to sample, for large bodies of text they are reliable enough to constitute one of the main tools of cryptanalysis. From such monogram frequencies one can calculate the frequencies which letter-pairs (Bi-grams) would have if the letters were in random sequence. The frequency of Bi-grams obtained from English usage are, of course, much different because the sequence of letters is not a random one. Cryptanalysis uses such frequency information to detect message structure.

DISCUSSION

Battery and cell failure data was extracted from the "Monthly Progress Report on National Aeronautics and Space Administration Space Cell Test Program" published by the Secondary Battery Section of the Quality Evaluation Department at NAD, Crane, Indiana, who is conducting the test program. The cut-off date for data used in this report was December 31, 1966.

As cells fail during cycling they are removed from the pack, opened, and a post-mortem examination is performed. The examination results are reported in descriptive English, such as the following report for Pack 5, Cell 3: "Low Voltage Discharge, Normal Voltage Charge, Still Under Pressure When Opened, Weak Tab to Plate Welds, Short Caused by Excess Scoring, Migration of Negative Plate Material, Separator Completely Deteriorated".

A simple code structure of failure characteristics, as defined by Crane, was devised. Table A shows the code legend. A maximum of seven coded failure characteristics per identified cell is entered into a punch card that also has pack and manufacturer identification. The maximum of seven coded failure characteristics is a convention to permit the failure characteristic history for all failed cells in one identified battery pack of up to ten cells to be represented by one punch card.

As example, Table B is a tabular representation of coded failure characteristic information provided in the Crane post-mortem reports. Examination of Table B will show that the reported failure characteristics for the previously mentioned Pack 5, Cell 3, are encoded BLQTKFC. In Table B, columns are cell numbers while row headings contain pack and manufacturer identification.

DISCUSSION (Cont'd)

It was assumed that much valuable information was contained in the mass of failure characteristic data. It was also noted that manual analysis of this conglomerate mass of data was difficult if not impossible. A technique, new and novel in industrial application, was applied to the data to extrapolate meaningful information. This technique is used in cryptology or cryptanalysis by intelligence organizations to extract a "message" from an apparently meaningless signal or body of data. A computer program was written to examine the data and to apply the cryptanalytic technique of measuring the combinatorial frequency of any three coded failure characteristics jointly with each other. The program output consisted of 1330 tally counters each of which indicated the occurrence frequency of a specific three-letter combination from all of the twenty-one letters used to code the failure characteristic data. (See Table A) The resultant tally tables are called "TRI-GRAM" frequency tables because each counter refers to joint frequency of three coded failure characteristics. There are 1330 three-letter permutations possible from the twenty-one code letters used.

"Tri-Gram" frequency tables were constructed for each of four manufacturers individually and for the same four manufacturers in total. Examples of portions of these "Tri-Gram" frequency tables follow as Table C. Pages C-1 through C-4 are the first sheet of each table constructed for the four individual manufacturers. Pages C-5 through C-18 are the complete "Tri-gram" frequency table, consisting of 1330 two-digit tally counters, for the total of the four manufacturers. It can be seen that Page C-5 is the total of pages C-1 through C-4.

Table D is a partial listing by manufacturer of total and partial "Tri-Gram" frequencies accountable to that identified manufacturer. The column headed "TRI-GRAM CODE" indicates the specific combination of coded failure characteristics. The column headed "PART" indicates that manufacturers portion of the total frequency, specified by the column headed "TOTAL", for all four manufacturers. Examination of Table D will show that individual manufacturer's cells were responsible for the total of many individual "Tri-Gram" failure characteristics or failure mechanisms. It may be seen that manufacturer No. 2, for example, is responsible for all occurrences of BCK:

B = Low Voltage Discharge

C = Separator Deteriorated, Dissolved, Etc.

K = Excess Scoring of Case

Manufacturer No. 2 was responsible for all occurrences of failure characteristic K.

Manufacturer No. 3 was responsible for all occurrences of BIO:

B = Low Voltage Discharge

I = Blistering on Positive Plate (s).

O = Ceramic Short

Manufacturer No. 3 was responsible for all occurrences of failure characteristic O.

Table E is included for reference only. Table E is listings, by manufacturer, of specific "Tri-Gram" codes with the frequency of 50% or more assignable to the indicated manufacturer. An asterisk (*) beneath a code indicates that 100% of that code frequency is assignable to the indicated manufacturer.

With this application of the "Tri-Gram Failure Characteristic Technique", it is possible to determine which single and/or triple combination of failure characteristics give insight to the identification of specific failure mechanisms assignable to individual designs or manufacturer.

NEW TECHNOLOGY

A new and novel application of a technique used in cryptology or cryptanalysis is being used to extract information from a mass of industrial data.

This technique has long been employed in the realm of intelligence organizations and secret agents to 'break' or 'crack' ciphers and codes. This is the first industrial application of this cryptanalytic process.

Cell failure characteristic data reported by NAD Crane was examined and assumed to contain much important information. This data covered several hundred battery cells with many types of failure characteristics for each cell. The resultant mass of data was too large, varied, and in unsuitable form for usual means of analysis; also, the data were so structured, unavoidably, to make manual analysis all but impossible.

The many kinds of failure characteristics reported by Crane were structured by Mauchly Systems, Inc., into a code of twenty-one possible types represented by the letters A through U. The cryptanalytic process of measuring the combinatorial frequency of any three code letters was programmed on a computer. The resultant computer output was a table of 1330 tally counters indicating the frequency of occurrence of each identified three-letter combination within the twenty-one letter code structure. Because this program indicated the combinatorial frequency of three letters, it was called the "Tri-Gram Failure Characteristic Technique".

The original assumption, that the cell failure characteristic reports contained much important information proved correct. Information extrapolated from the mass of data indicated that certain failure characteristics and failure mechanisms could be assigned to specific manufacturers and cell designs.

NEW TECHNOLOGY (Cont'd)

Application of the "Tri-Gram Failure Characteristic Technique", to any coded data, enables correlation of failure characteristics and failure mechanisms to manufacture/design defects and to environmental effects.

PROGRAM FOR NEXT REPORTING INTERVAL

1. "Tri-Gram" Tables:

   "Tri-Gram" frequency tables will be constructed for several individual and combined cycling environmental parameters. Effort will be made to determine environmental effect (s) on failure characteristics and failure mechanisms.

2. Temperature:

   A temperature-failure analysis is in progress. Effort will be made to ascertain if cell-temperature fluctuation-patterns are indicative of impending cell failure.

CONCLUSIONS AND RECOMMENDATIONS

Much valuable information concerning manufacturer/design effect on failure characteristics and failure mechanisms has been gained by application of the technique described earlier in this report. This information can be used by cell manufacturers to assay the extent of possible defects in their product within all operating conditions and to evaluate the interrelating effects of new components with each other and with standard parts. Specific areas of concern are pinpointed for attention by the cell-design and quality control engineer. As example, manufacturer No. 2 was responsible for all cell failures involving "Excess Scoring of Case", manufacturer No. 3 was responsible for all cell failures involving "Ceramic Short", and manufacturer No. 4 was responsible for all cell failures involving "Extraneous Material Between Plates".

The ultimate purpose of this work is to provide the engineer with a method to assess the potentialities of space-battery-cells relative to various environmental and functional parameters, permiting correlation and selection within space mission operational requirements and constraints.

CONCLUSIONS AND RECOMMENDATIONS (Cont'd)

The "Tri-Gram" frequency technique is limited only by the necessity for coded input. The major advantage of this technique is the capability gained to extract information "hidden" within a large mass of varied data.

It is recommended that cell post-mortem reports be expanded to include more physical and chemical data such as plate weight-loss and electrolyte PH, etc. Such additional information should further pinpoint specific failure mechanisms and permit earlier and more exact prediction capabilities.

TABLES

FAILURE CHARACTERISTICS

A. Low Voltage Charge.

B. Low Voltage Discharge.

C. Separator: Deteriorated, Dissolved, Burned, Pinpoint Penetration, Short.

D. Plate Material Shorted Through Separator.

E. Separator Impregnated With Negative Plate Material.

F. Migration of Positive and/or Negative Plate Material.

G. Extraneous Material Between Plates.

H. Deposit on Positive and/or Negative Terminals.

I. Blistering on Positive Plate(s).

J. Plate(s) Stuck To Case.

K. Excess Scoring of Case.

L. High Pressure, Bulge, Convex Side(s)

M. Concave Side(s), Short(s) Due To Internal Shift.

N. Broken Seal(s): Ceramic, Glass

O. Ceramic Short

P. Electrolyte Leak, Weight Loss, Separator Dry, Electrolyte Shorted Out Cell.

Q. Tab(s): Burned, Broken, Welds Weak.

R. Third Electrode Shorted to Plate.

S. Cell Blew Up.

T. Circuit: Short, Open.

U. High Voltage Charge.

Table A

EXAMPLE OF FAILURE CHARACTERISTIC INFORMATION
PROVIDED BY CRANE AND CODED BY MAUCHLY SYSTEMS, INC.

PACK		CELL NUMBER 1	2	3	4	5	6	7	8	9	10
1	2	BUQKT		BQKFC	BUCP	BHKFC	BTKFC				BHQTKFC
2	2	BLKFC	ABKDQC			BPLCD	BEFCQL	ABDQKCE			TPLDCQ
3	4		ABPQ		BCEI	BUTGD	BPCD	BPCD		BPCTQ	BPE
4	4	ABCL		AC			ABPE	BPL	ABPL		ABPCF
5	2		BUKFTC	BLQTKFC							
6	2				DTQ		BQKFC	BKTQC	BE	BLKFC	ABCD
7	4	APNCFQ	APEFCQ	APQC		TPQEC	ABPCEQ	APFC			
8	4	ACE	ABPCEQ				ABPE	ABPQCE	APQ	ABPCEF	APQC
11	3	THFIC	BUHFICP	ROICP							
13	3	BUPL	ABOCEIL		ABOIC	ABOI		ABOI			BUPL
14	3	BUPL	BUO	ABO	BUPL	PMLN		BO			
15	1				BFCI	BHFIC		ABIFC	ABIFC	BFCI	BFCI
16	1	BDCET			ABEC	ABEC	BCDT	BQ			ABEC
17	3	ABOL	ABCIL	BULO		BUO				ABOIL	ABO
18	3	ABOIE		BPL		ABOI	BPMO	BULO		BUO	
25	2	ABKFC	ABFCQ	BCD	BLTKFC	AUCKT	BTCG				
26	2	D		TK	ABCD		BLQD	BLQKC		TCQD	
27	4		ACE	ABPCF				ALDF	APDCF	BUPCE	APDCQ
28	4	ABTD	APQ	BUQ	ABTIE	BUP	ABDQ	APL	APL	ABDQ	AUQ
29	2	TQDK				BHQKFC	BHPQKDC	ABCQ	BCK		
30	2	TC			ABCQK			CT	ABPTKFC	BCKQA	ABFC
31	4	ABPGCQ	BUDC	ABPDCEQ			ABDGECQ		BUPCEQ	ABPC	ABPDCQ
32	4	BPT		BP	ABPT		BQH	PTL		BUPDQ	
33	5	P	P	P	P				P		P
37	3			ABPO	ABOI		BUCEIO	BOPIC	ABPO		BOI
38	3		ABLO	BUP		BT	ABPO		ABO	BAHO	
39	1	BHQFC	BPTQUC			BPQFC	BTPQUC	BQU	BC		
40	1		BUPQT	BUTQC		BUQ	BUPTCQ	BUTCQ	BPF		BUFT
41	3		BO	BOI			BO	BOI	BO	BUO	
42	3	ABLOP			ABPIFCO		BPC	ABO	BO	BUO	
43	1			BUTCQ	BTCQA		Q	QTC		QCFE	QCFE
44	1	THC	BUHFCI	BFC			Q		BUCI		ABFCI
50	2			ABHKFT		ABDKF					
52	4			TGDFC				BUFCE	ABLEFC	ABFEC	BLCF
57	5	P	P	P	P	P	P	P	P	P	P
66	3			BOLMIP	BHLMTOF	BULHNIC	BULMNP	ABPEILM	ABMO		

Table B

MANUFACTURER NO. 1 15 PACKS 66 CELLS

AB	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	1
	17	03	04	08	00	02	06	00	00	02	00	00	00	00	02	00	00	01	00	1
AC	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U		2
	03	04	08	00	02	06	00	00	02	00	00	00	00	02	00	00	01	00		2
AD	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U			3
	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00			3
AE	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U				4
	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00				4
AF	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U					5
	00	01	06	00	00	02	00	00	00	00	01	00	00	00	00					5
AG	H	I	J	K	L	M	N	O	P	Q	R	S	T	U						6
	00	00	00	00	00	00	00	00	00	00	00	00	00	00						6
AH	I	J	K	L	M	N	O	P	Q	R	S	T	U							7
	01	00	00	00	00	00	00	00	00	00	00	00	00							7
AI	J	K	L	M	N	O	P	Q	R	S	T	U								8
	00	00	00	00	00	00	00	01	00	00	00	00								8
AJ	K	L	M	N	O	P	Q	R	S	T	U									9
	00	00	00	00	00	00	00	00	00	00	00									9
AK	L	M	N	O	P	Q	R	S	T	U										10
	00	00	00	00	00	00	00	00	00	00										10
AL	M	N	O	P	Q	R	S	T	U											11
	00	00	00	00	00	00	00	00	00											11
AM	N	O	P	Q	R	S	T	U												12
	00	00	00	00	00	00	00	00												12
AN	O	P	Q	R	S	T	U													13
	00	00	00	00	00	00	00													13
AO	P	Q	R	S	T	U														14
	00	00	00	00	00	00														14
AP	Q	R	S	T	U															15
	00	00	00	00	00															15
AQ	R	S	T	U																16
	00	00	01	00																16
AR	S	T	U																	17
	00	00	00																	17
AS	T	U																		18
	00	00																		18
AT	U																			19
	00																			19

First page of a "Tri-Gram" table. This page features every three letter combination that contains the letter A for the indicated manufacturer.

Table C-1

MANUFACTURER NO. 2   11 PACKS   47 CELLS

```
AB  C  D  E  F  G  H  I  J  K  L  M  N  O  P  Q  R  S  T  U      1
   11 05 01 05 00 01 00 00 08 00 00 00 00 01 06 00 00 02 00      1
AC  D  E  F  G  H  I  J  K  L  M  N  O  P  Q  R  S  T  U         2
   04 01 03 00 00 00 00 06 00 00 00 00 01 06 00 00 01 00         2
AD  E  F  G  H  I  J  K  L  M  N  O  P  Q  R  S  T  U            3
   01 01 00 00 00 00 03 00 00 00 00 00 02 00 00 00 00            3
AE  F  G  H  I  J  K  L  M  N  O  P  Q  R  S  T  U               4
   00 00 00 00 00 01 00 00 00 00 00 01 00 00 00 00               4
AF  G  H  I  J  K  L  M  N  O  P  Q  R  S  T  U                  5
   00 01 00 00 04 00 00 00 00 01 01 00 00 02 00                  5
AG  H  I  J  K  L  M  N  O  P  Q  R  S  T  U                     6
   00 00 00 00 00 00 00 00 00 00 00 00 00 00                     6
AH  I  J  K  L  M  N  O  P  Q  R  S  T  U                        7
   00 00 01 00 00 00 00 00 00 00 00 01 00                        7
AI  J  K  L  M  N  O  P  Q  R  S  T  U                           8
   00 00 00 00 00 00 00 00 00 00 00 00                           8
AJ  K  L  M  N  O  P  Q  R  S  T  U                              9
   00 00 00 00 00 00 00 00 00 00 00                              9
AK  L  M  N  O  P  Q  R  S  T  U                                10
   00 00 00 00 01 04 00 00 02 00                                10
AL  M  N  O  P  Q  R  S  T  U                                   11
   00 00 00 00 00 00 00 00 00                                   11
AM  N  O  P  Q  R  S  T  U                                      12
   00 00 00 00 00 00 00 00                                      12
AN  O  P  Q  R  S  T  U                                         13
   00 00 00 00 00 00 00                                         13
AO  P  Q  R  S  T  U                                            14
   00 00 00 00 00 00                                            14
AP  Q  R  S  T  U                                               15
   00 00 00 01 00                                               15
AQ  R  S  T  U                                                  16
   00 00 00 00                                                  16
AR  S  T  U                                                     17
   00 00 00                                                     17
AS  T  U                                                        18
   00 00                                                        18
AT  U                                                           19
   00                                                           19
```

MANUFACTURER NO. 3 49 PACKS 172 CELLS

```
AB  C  D  E  F  G  H  I  J  K  L  M  N  O  P  Q  R  S  T  U      1
   26 05 05 13 00 06 29 00 00 24 08 00 34 14 04 00 00 04 00      1
AC  D  E  F  G  H  I  J  K  L  M  N  O  P  Q  R  S  T  U         2
   04 01 12 00 03 15 00 00 13 03 00 09 06 04 00 00 04 00         2
AD  E  F  G  H  I  J  K  L  M  N  O  P  Q  R  S  T  U            3
   00 01 00 01 03 00 00 02 01 00 01 01 00 00 00 01 00            3
AE  F  G  H  I  J  K  L  M  N  O  P  Q  R  S  T  U               4
   00 00 00 05 00 00 04 01 00 04 01 00 00 00 00 00               4
AF  G  H  I  J  K  L  M  N  O  P  Q  R  S  T  U                  5
   00 04 05 00 00 06 02 00 03 05 04 00 00 01 00                  5
AG  H  I  J  K  L  M  N  O  P  Q  R  S  T  U                     6
   00 00 00 00 00 00 00 00 00 00 00 00 00 00                     6
AH  I  J  K  L  M  N  O  P  Q  R  S  T  U                        7
   01 00 00 02 03 00 02 01 00 00 00 01 00                        7
AI  J  K  L  M  N  O  P  Q  R  S  T  U                           8
   00 00 15 04 00 18 05 02 00 00 02 00                           8
AJ  K  L  M  N  O  P  Q  R  S  T  U                              9
   00 00 00 00 00 00 00 00 00 00 00                              9
AK  L  M  N  O  P  Q  R  S  T  U                                10
   00 00 00 00 00 00 00 00 00 00                                10
AL  M  N  O  P  Q  R  S  T  U                                   11
   02 00 13 05 02 00 00 02 00                                   11
AM  N  O  P  Q  R  S  T  U                                      12
   00 02 02 00 00 00 02 00                                      12
AN  O  P  Q  R  S  T  U                                         13
   00 00 00 00 00 00 00                                         13
AO  P  Q  R  S  T  U                                            14
   07 01 00 00 00 00                                            14
AP  Q  R  S  T  U                                               15
   01 00 00 00 00                                               15
AQ  R  S  T  U                                                  16
   00 00 00 00                                                  16
AR  S  T  U                                                     17
   00 00 00                                                     17
AS  T  U                                                        18
   00 00                                                        18
AT  U                                                           19
   00                                                           19
```

MANUFACTURER NO. 4 17 PACKS 76 CELLS

AB	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	1
	27	16	11	11	03	01	07	00	00	21	00	00	00	15	12	00	00	18	00	1
AC	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U		2
	07	11	15	02	01	05	00	00	12	00	01	00	17	14	00	00	08	00		2
AD	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U			3
	02	02	02	00	02	00	00	10	00	00	00	04	07	00	00	09	00			3
AE	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U				4
	04	01	00	01	00	00	01	00	00	00	08	06	00	00	01	00				4
AF	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U					5
	00	01	02	00	00	07	00	01	00	07	03	00	00	03	00					5
AG	H	I	J	K	L	M	N	O	P	Q	R	S	T	U						6
	00	00	00	00	01	00	00	00	01	02	00	00	01	00						6
AH	I	J	K	L	M	N	O	P	Q	R	S	T	U							7
	00	00	00	01	00	00	00	00	00	00	00	01	00							7
AI	J	K	L	M	N	O	P	Q	R	S	T	U								8
	00	00	05	00	00	00	00	00	00	00	03	00								8
AJ	K	L	M	N	O	P	Q	R	S	T	U									9
	00	00	00	00	00	00	00	00	00	00	00									9
AK	L	M	N	O	P	Q	R	S	T	U										10
	00	00	00	00	00	00	00	00	00	00										10
AL	M	N	O	P	Q	R	S	T	U											11
	00	00	00	03	01	00	00	13	00											11
AM	N	O	P	Q	R	S	T	U												12
	00	00	00	00	00	00	00	00												12
AN	O	P	Q	R	S	T	U													13
	00	01	01	00	00	00	00													13
AO	P	Q	R	S	T	U														14
	00	00	00	00	00	00														14
AP	Q	R	S	T	U															15
	14	00	00	01	00															15
AQ	R	S	T	U																16
	00	00	00	00																16
AR	S	T	U																	17
	00	00	00																	17
AS	T	U																		18
	00	00																		18
AT	U																			19
	00																			19

MANUFACTURERS NO. 1,2,3,4 92 PACKS 361 CELLS

AB	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	1
	81	29	21	37	03	10	42	00	08	47	08	00	34	30	24	00	00	25	00	1
AC	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U		2
	18	17	38	02	06	26	00	06	27	03	01	09	24	26	00	00	14	00		2
AD	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U			3
	03	04	02	01	05	00	03	12	01	00	01	05	09	00	00	10	00			3
AE	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U				4
	04	01	00	06	00	01	05	01	00	04	09	07	00	00	01	00				4
AF	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U					5
	00	07	13	00	04	15	02	01	03	13	09	00	00	06	00					5
AG	H	I	J	K	L	M	N	O	P	Q	R	S	T	U						6
	00	00	00	00	01	00	00	00	01	02	00	00	01	00						6
AH	I	J	K	L	M	N	O	P	Q	R	S	T	U							7
	02	00	01	03	03	00	02	01	00	00	00	03	00							7
AI	J	K	L	M	N	O	P	Q	R	S	T	U								8
	00	00	20	04	00	18	05	03	00	00	05	00								8
AJ	K	L	M	N	O	P	Q	R	S	T	U									9
	00	00	00	00	00	00	00	00	00	00	00									9
AK	L	M	N	O	P	Q	R	S	T	U										10
	00	00	00	00	01	04	00	00	02	00										10
AL	M	N	O	P	Q	R	S	T	U											11
	02	00	13	08	03	00	00	15	00											11
AM	N	O	P	Q	R	S	T	U												12
	00	02	02	00	00	00	02	00												12
AN	O	P	Q	R	S	T	U													13
	00	01	01	00	00	00	00													13
AO	P	Q	R	S	T	U														14
	07	01	00	00	00	00														14
AP	Q	R	S	T	U															15
	15	00	00	02	00															15
AQ	R	S	T	U																16
	00	00	01	00																16
AR	S	T	U																	17
	00	00	00																	17
AS	T	U																		18
	00	00																		18
AT	U																			19
	00																			19

Every entry on this page is the sum of the corresponding entries on pages C-1 through C-4.

Pages C-5 through C-18 are a listing of a complete "Tri-Gram" frequency table. This table specifies the total occurrences for all four manufacturers.

BC	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	20
	27	21	80	04	23	47	00	22	43	03	01	13	37	50	00	00	31	24	20
BD	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U		21
	04	05	03	02	08	00	04	16	02	01	01	09	11	00	00	14	05		21
BE	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U			22
	05	01	00	09	01	01	06	01	00	05	11	08	00	00	02	05			22
BF	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U				23
	00	22	30	00	15	29	04	00	06	23	24	00	00	13	14				23
BG	H	I	J	K	L	M	N	O	P	Q	R	S	T	U					24
	00	01	00	00	01	00	00	00	01	02	00	00	03	01					24
BH	I	J	K	L	M	N	O	P	Q	R	S	T	U						25
	08	00	05	08	05	01	05	07	07	00	00	05	06						25
BI	J	K	L	M	N	O	P	Q	R	S	T	U							26
	01	00	31	06	02	26	16	05	00	00	05	12							26
BJ	K	L	M	N	O	P	Q	R	S	T	U								27
	00	00	00	00	00	00	00	00	00	00	01								27
BK	L	M	N	O	P	Q	R	S	T	U									28
	05	00	00	00	02	13	00	00	10	03									28
BL	M	N	O	P	Q	R	S	T	U										29
	06	05	19	24	09	00	00	18	20										29
BM	N	O	P	Q	R	S	T	U											30
	03	05	10	01	00	00	05	03											30
BN	O	P	Q	R	S	T	U												31
	00	06	00	00	00	01	05												31
BO	P	Q	R	S	T	U													32
	11	02	00	00	01	10													32
BP	Q	R	S	T	U														33
	21	00	00	10	31														33
BQ	R	S	T	U															34
	00	00	13	19															34
BR	S	T	U																35
	00	00	00																35
BS	T	U																	36
	00	00																	36
BT	U																		37
	12																		37

CD	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	38
	04	09	02	02	04	00	04	06	01	00	00	10	10	00	00	11	03	38
CE	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U		39
	08	01	00	03	00	01	03	00	00	02	09	12	00	00	02	04		39
CF	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U			40
	02	22	28	00	14	34	03	02	07	21	30	00	00	28	08			40
CG	H	I	J	K	L	M	N	O	P	Q	R	S	T	U				41
	01	03	00	00	02	00	01	01	01	02	00	00	06	00				41
CH	I	J	K	L	M	N	O	P	Q	R	S	T	U					42
	11	01	04	09	04	03	04	05	05	00	00	14	03					42
CI	J	K	L	M	N	O	P	Q	R	S	T	U						43
	00	00	23	04	01	12	08	05	01	00	16	05						43
CJ	K	L	M	N	O	P	Q	R	S	T	U							44
	00	02	00	00	00	00	00	00	00	00	00							44
CK	L	M	N	O	P	Q	R	S	T	U								45
	05	00	00	00	02	12	00	00	09	02								45
CL	M	N	O	P	Q	R	S	T	U									46
	03	01	05	05	11	00	00	34	03									46
CM	N	O	P	Q	R	S	T	U										47
	00	01	00	01	00	00	06	00										47
CN	O	P	Q	R	S	T	U											48
	01	02	01	00	00	02	01											48
CO	P	Q	R	S	T	U												49
	05	02	01	00	03	01												49
CP	Q	R	S	T	U													50
	24	01	00	10	08													50
CQ	R	S	T	U														51
	00	00	18	11														51
CR	S	T	U															52
	00	00	00															52
CS	T	U																53
	00	00																53
CT	U																	54
	08																	54

DE	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	55
	00	01	00	00	00	01	00	00	00	00	01	03	00	00	01	00	55
DF	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U		56
	01	01	01	00	02	03	00	00	00	01	00	00	00	04	02		56
DG	H	I	J	K	L	M	N	O	P	Q	R	S	T	U			57
	00	00	00	00	01	00	00	00	00	01	00	00	03	01			57
DH	I	J	K	L	M	N	O	P	Q	R	S	T	U				58
	00	00	01	00	00	00	00	01	01	00	00	00	00				58
DI	J	K	L	M	N	O	P	Q	R	S	T	U					59
	00	00	07	01	00	01	01	00	00	00	03	00					59
DJ	K	L	M	N	O	P	Q	R	S	T	U						60
	00	00	00	00	00	00	00	00	00	00	00						60
DK	L	M	N	O	P	Q	R	S	T	U							61
	00	00	00	00	01	04	00	00	02	00							61
DL	M	N	O	P	Q	R	S	T	U								62
	00	00	01	03	02	00	00	11	00								62
DM	N	O	P	Q	R	S	T	U									63
	01	00	01	00	00	00	02	00									63
DN	O	P	Q	R	S	T	U										64
	00	01	00	00	00	01	00										64
DO	P	Q	R	S	T	U											65
	01	00	00	00	00	00											65
DP	Q	R	S	T	U												66
	06	00	00	03	01												66
DQ	R	S	T	U													67
	00	00	04	01													67
DR	S	T	U														68
	00	00	00														68
DS	T	U															69
	00	00															69
DT	U																70
	01																70

```
EF  G  H  I  J  K  L  M  N  O  P  Q  R  S  T  U                              71
    00 00 00 00 00 02 00 00 00 02 04 00 00 00 01                              71
EG  H  I  J  K  L  M  N  O  P  Q  R  S  T  U                                  72
    00 00 00 00 00 00 00 00 00 01 00 00 00 00                                 72
EH  I  J  K  L  M  N  O  P  Q  R  S  T  U                                     73
    00 00 00 00 00 00 00 00 00 00 00 00 00                                    73
EI  J  K  L  M  N  O  P  Q  R  S  T  U                                        74
    01 00 04 01 00 05 01 00 00 00 01 02                                       74
EJ  K  L  M  N  O  P  Q  R  S  T  U                                           75
    00 00 00 00 00 00 00 00 00 00 01                                          75
EK  L  M  N  O  P  Q  R  S  T  U                                              76
    00 00 00 00 00 01 00 00 00 00                                             76
EL  M  N  O  P  Q  R  S  T  U                                                 77
    01 00 03 01 01 00 00 00 00                                                77
EM  N  O  P  Q  R  S  T  U                                                    78
    00 00 01 00 00 00 00 00                                                   78
EN  O  P  Q  R  S  T  U                                                       79
    00 00 00 00 00 00 00                                                      79
EO  P  Q  R  S  T  U                                                          80
    00 00 00 00 00 01                                                         80
EP  Q  R  S  T  U                                                             81
    07 00 00 02 02                                                            81
EQ  R  S  T  U                                                                82
    00 00 01 01                                                               82
ER  S  T  U                                                                   83
    00 00 00                                                                  83
ES  T  U                                                                      84
    00 00                                                                     84
ET  U                                                                         85
    00                                                                        85
```

FG	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	86
	00	00	00	00	00	00	00	01	00	00	00	00	02	00	86
FH	I	J	K	L	M	N	O	P	Q	R	S	T	U		87
	09	00	04	07	05	01	04	06	05	00	00	10	04		87
FI	J	K	L	M	N	O	P	Q	R	S	T	U			88
	00	00	10	01	00	04	09	05	00	00	03	06			88
FJ	K	L	M	N	O	P	Q	R	S	T	U				89
	00	00	00	00	00	00	00	00	00	00	00				89
FK	L	M	N	O	P	Q	R	S	T	U					90
	04	00	00	00	01	05	00	00	08	01					90
FL	M	N	O	P	Q	R	S	T	U						91
	03	00	02	04	08	01	00	15	03						91
FM	N	O	P	Q	R	S	T	U							92
	00	02	01	02	00	00	03	01							92
FN	O	P	Q	R	S	T	U								93
	01	02	01	00	00	01	00								93
FO	P	Q	R	S	T	U									94
	02	02	00	00	03	00									94
FP	Q	R	S	T	U										95
	08	01	00	02	07										95
FQ	R	S	T	U											96
	00	00	05	03											96
FR	S	T	U												97
	00	00	00												97
FS	T	U													98
	00	00													98
FT	U														99
	02														99

```
GH  I  J  K  L  M  N  O  P  Q  R  S  T  U                100
   00 00 00 00 00 01 00 00 00 00 00 01 00                100
GI  J  K  L  M  N  O  P  Q  R  S  T  U                   101
   00 00 02 00 00 00 00 00 00 00 02 00                   101
GJ  K  L  M  N  O  P  Q  R  S  T  U                      102
   00 00 00 00 00 00 00 00 00 00 00                      102
GK  L  M  N  O  P  Q  R  S  T  U                         103
   00 00 00 00 00 00 00 00 00 00                         103
GL  M  N  O  P  Q  R  S  T  U                            104
   00 00 00 00 00 00 00 03 00                            104
GM  N  O  P  Q  R  S  T  U                               105
   00 00 00 00 00 00 00 00                               105
GN  O  P  Q  R  S  T  U                                  106
   00 00 00 00 00 01 00                                  106
GO  P  Q  R  S  T  U                                     107
   00 00 00 00 01 00                                     107
GP  Q  R  S  T  U                                        108
   01 00 00 00 00                                        108
GQ  R  S  T  U                                           109
   00 00 00 00                                           109
GR  S  T  U                                              110
   00 00 00                                              110
GS  T  U                                                 111
   00 00                                                 111
GT  U                                                    112
   01                                                    112
```

HI	J	K	L	M	N	O	P	Q	R	S	T	U	113
	00	00	07	03	01	01	02	00	00	00	05	04	113
HJ	K	L	M	N	O	P	Q	R	S	T	U		114
	00	01	00	00	00	00	00	00	00	00	00		114
HK	L	M	N	O	P	Q	R	S	T	U			115
	00	00	00	00	01	03	00	00	02	00			115
HL	M	N	O	P	Q	R	S	T	U				116
	04	01	03	01	00	00	00	07	03				116
HM	N	O	P	Q	R	S	T	U					117
	00	02	02	01	00	00	04	01					117
HN	O	P	Q	R	S	T	U						118
	01	01	00	00	00	02	01						118
HO	P	Q	R	S	T	U							119
	01	00	00	00	03	01							119
HP	Q	R	S	T	U								120
	03	00	00	01	03								120
HQ	R	S	T	U									121
	00	00	01	01									121
HR	S	T	U										122
	00	00	00										122
HS	T	U											123
	00	00											123
HT	U												124
	00												124

```
IJ  K  L  M  N  O  P  Q  R  S  T  U                    125
    00 00 00 00 00 00 00 00 00 00 01                    125
IK  L  M  N  O  P  Q  R  S  T  U                       126
    00 00 00 00 00 00 00 00 00 00                       126
IL  M  N  O  P  Q  R  S  T  U                          127
    06 02 11 09 01 00 00 11 05                          127
IM  N  O  P  Q  R  S  T  U                             128
    00 01 03 00 00 00 04 01                             128
IN  O  P  Q  R  S  T  U                                129
    00 01 00 00 00 00 02                                129
IO  P  Q  R  S  T  U                                   130
    05 02 01 00 00 01                                   130
IP  Q  R  S  T  U                                      131
    01 01 00 02 07                                      131
IQ  R  S  T  U                                         132
    00 00 00 00                                         132
IR  S  T  U                                            133
    00 00 00                                            133
IS  T  U                                               134
    00 00                                               134
IT  U                                                  135
    00                                                  135
```

JK	L	M	N	O	P	Q	R	S	T	U	136
	00	00	00	00	00	00	00	00	00	00	136
JL	M	N	O	P	Q	R	S	T	U		137
	00	00	00	00	00	00	00	00	00		137
JM	N	O	P	Q	R	S	T	U			138
	00	00	00	00	00	00	00	00			138
JN	O	P	Q	R	S	T	U				139
	00	00	00	00	00	00	00				139
JO	P	Q	R	S	T	U					140
	00	00	00	00	00	00					140
JP	Q	R	S	T	U						141
	00	00	00	00	00						141
JQ	R	S	T	U							142
	00	00	00	00							142
JR	S	T	U								143
	00	00	00								143
JS	T	U									144
	00	00									144
JT	U										145
	00										145

```
KL  M  N  O  P  Q  R  S  T  U                                146
    00 00 00 00 02 00 00 02 00                               146
KM  N  O  P  Q  R  S  T  U                                   147
    00 00 00 00 00 00 00 00                                  147
KN  O  P  Q  R  S  T  U                                      148
    00 00 00 00 00 00 00                                     148
KO  P  Q  R  S  T  U                                         149
    00 00 00 00 00 00                                        149
KP  Q  R  S  T  U                                            150
    01 00 00 01 00                                           150
KQ  R  S  T  U                                               151
    00 00 05 01                                              151
KR  S  T  U                                                  152
    00 00 00                                                 152
KS  T  U                                                     153
    00 00                                                    153
KT  U                                                        154
    03                                                       154
```

LM	N	O	P	Q	R	S	T	U	155
	02	02	05	01	00	00	04	02	155
LN	O	P	Q	R	S	T	U		156
	00	05	00	00	00	00	05		156
LO	P	Q	R	S	T	U			157
	04	00	00	00	01	03			157
LP	Q	R	S	T	U				158
	01	01	00	03	14				158
LQ	R	S	T	U					159
	00	00	04	02					159
LR	S	T	U						160
	00	00	00						160
LS	T	U							161
	00	00							161
LT	U								162
	00								162

MN	O	P	Q	R	S	T	U	163
	00	04	00	00	00	01	01	163
MO	P	Q	R	S	T	U		164
	02	00	00	00	01	00		164
MP	Q	R	S	T	U			165
	01	00	00	02	03			165
MQ	R	S	T	U				166
	00	00	01	01				166
MR	S	T	U					167
	00	00	00					167
MS	T	U						168
	00	00						168
MT	U							169
	00							169

NO	P	Q	R	S	T	U	170
	01	00	00	00	01	00	170
NP	Q	R	S	T	U		171
	01	00	00	02	04		171
NQ	R	S	T	U			172
	00	00	00	00			172
NR	S	T	U				173
	00	00	00				173
NS	T	U					174
	00	00					174
NT	U						175
	00						175

OP	Q	R	S	T	U		176
	00	01	00	01	01		176
OQ	R	S	T	U			177
	00	00	00	00			177
OR	S	T	U				178
	00	00	00				178
OS	T	U					179
	00	00					179
OT	U						180
	00						180

PQ	R	S	T	U	181
	00	00	07	08	181
PR	S	T	U		182
	00	00	00		182
PS	T	U			183
	00	00			183
PT	U				184
	04				184
QR	S	T	U		185
	00	00	00		185
QS	T	U			186
	00	00			186
QT	U				187
	08				187
RS	T	U			188
	00	00			188
RT	U				189
	00				189
ST	U				190
	00				190

MANUFACTURER NO. 1

15 PACKS

66 CELLS

TRI-GRAM CODE	PART	TOTAL
BQT	8	13
BTU	8	12
CQU	6	11
CTU	6	8
PQT	4	7
PQU	4	8
PTU	4	4
QTU	7	8

TABLE D-1

MANUFACTURER NO. 2

11 PACKS

47 CELLS

TRI-GRAM CODE	PART	TOTAL
ABK	8	8
AKQ	4	4
BCK	22	22
BDK	4	4
BFK	15	15
BFT	7	13
BKL	5	5
BKQ	13	13
CKQ	12	12
DFK	2	2
DQT	4	4
KQT	5	5
KTU	3	3
LQT	2	4

TABLE D-2

MANUFACTURER NO. 3

49 PACKS

172 CELLS

TRI-GRAM CODE	PART	TOTAL
ABH	6	10
ABI	29	42
ABO	34	34
ACI	15	26
AIL	15	20
AIO	18	18
BCI	28	47
BFH	11	22
BIL	23	31
BIO	26	26
BIP	16	16
BLP	21	24
CHT	10	14
EIO	5	5
FIL	7	10
ILO	11	11
LPU	14	14
LQT	2	4
MPU	3	3
NPU	4	4

TABLE D-3

MANUFACTURER NO. 4

17 PACKS

76 CELLS

TRI-GRAM CODE	PART	TOTAL
ABD	16	29
ABP	15	30
ABQ	12	24
ACP	17	24
BDL	11	16
BEP	10	11
BLT	13	18
CEP	9	9
CPQ	14	24
DLT	8	11
EPQ	7	7
GIL	2	2
GLT	3	3

TABLE D-4

TRI-GRAM FAILURE CHARACTERISTIC CODES THAT ASSIGN 50% OR MORE OF THEIR TOTAL FREQUENCY COUNT TO THE IDENTIFIED MANUFACTURER.

AN * BELOW TRI-GRAM CODE DENOTES THAT THE INDICATED MANUFACTURER IS ACCOUNTABLE FOR THE TOTAL FREQUENCY OF THAT SPECIFIC CODE.

MANUFACTURER NO. 1
15 PACKS 66 CELLS

1	AHI	AQT	BQT	BTU	CET	CQU	CTU	DET	FTU	PQT	PQU	PTU	QTU
	*	*						*				*	

MANUFACTURER NO. 2
11 PACKS 47 CELLS

2	ABK	AEK	AHK	AKP	AKQ	AKT	APT	BCK	BDK	BEK	BFK	BFT	BHK	BKL	BKP	BKQ	BKT	BKU	CDH
	*	*	*	*	*	*		*	*	*	*		*	*	*	*	*	*	
2	CDK	CDQ	CEK	CFK	CHK	CHQ	CKL	CKP	CKQ	CKT	CKU	DEK	DFK	DHK	DHP	DHQ	DKP	DKQ	DKT
	*		*	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*
2	DLP	DLQ	DQT	EFL	EKQ	ELQ	FHK	FKL	FKP	FKQ	FKT	FKU	FPT	FTU	HKP	HKQ	HKT	HQT	KLQ
		*	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2	KLT	KPQ	KPT	KQT	KQU	KTU	LPQ	LQT											
	*	*	*	*	*	*	*												

TABLE E-1

MANUFACTURER NO. 3
49 PACKS 172 CELLS

3	ABH	ABI	ABM	ABO	ACH	ACI	ACM	ACO	ADI	ADM	ADO	AEI	AEL	AEM	AFH	AFM	AFO	AHI	AHL
			*	*			*	*		*	*			*		*	*		
3	AHM	AHO	AHP	AIL	AIM	AIO	AIP	AIQ	ALM	ALO	ALP	ALQ	AMO	AMP	AMT	AOP	AOQ	BCI	BCM
	*	*	*		*	*	*		*	*			*	*	*	*	*		*
3	BCN	BCO	BDF	BDH	BDI	BDM	BDN	BDO	BEI	BEJ	BEL	BEM	BEO	BFH	BFI	BFM	BFO	BFP	BFQ
	*	*				*	*	*		*		*	*			*	*		
3	BFU	BGI	BHI	BHL	BHM	BHN	BHO	BHP	BHU	BIJ	BIL	BIM	BIN	BIO	BIP	BIQ	BIU	BLM	BLN
		*			*	*	*			*		*	*	*	*			*	*
3	BLO	BLP	BLU	BMN	BMO	BMP	BMQ	BMT	BMU	BNP	BNT	BNU	BOP	BOQ	BOT	BOU	BPU	CDF	CDH
	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*			
3	CDI	CDL	CDM	CEI	CEO	CFG	CFH	CFM	CFN	CFO	CFP	CFQ	CFT	CFU	CGH	CGN	CGO	CHI	CHJ
			*		*			*		*					*	*	*		*
3	CHL	CHM	CHN	CHO	CHP	CHT	CHU	CIL	CIM	CIN	CIO	CIP	CIQ	CIR	CIT	CIU	CJL	CLM	CLN
		*	*	*					*	*	*	*		*			*	*	*
3	CLO	CLP	CLQ	CLU	CMO	CMQ	CMT	CNO	CNP	CNT	CNU	COP	COQ	COR	COT	COU	CPR	DFH	DFI
	*			*	*	*	*	*		*	*	*	*	*	*	*	*	*	*
3	DFL	DFT	DFU	DIM	DIO	DIP	DIT	DLO	DMN	DMP	DMT	DNP	DNT	DOP	EIJ	EIL	EIM	EIO	EIP
			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
3	EIU	ELM	ELO	ELP	EMP	EOU	EPT	FGO	FGT	FHI	FHL	FHM	FHN	FHO	FHP	FHT	FHU	FIL	FIM
	*	*	*	*	*	*		*				*	*	*	*				*
3	FIO	FIP	FIQ	FIT	FIU	FLM	FLO	FLP	FLQ	FLR	FLT	FLU	FMO	FMP	FMQ	FMT	FMU	FNO	FNP
	*	*				*	*	*		*		*	*	*	*	*	*	*	*
3	FNT	FOP	FOQ	FOT	FPQ	FPR	FPT	FPU	FQT	FQU	GHN	GHT	GNT	GOT	HIL	HIM	HIN	HIO	HIP
	*	*	*	*		*		*		*	*	*	*	*	*	*	*	*	*

TABLE E-2

3	HIT	HIU	HJL	HLM	HLN	HLO	HLP	HLT	HLU	HMO	HMP	HMQ	HMT	HMU	HNO	HNP	HNT	HNU	HOP
			*	*	*	*	*		*	*	*	*	*	*	*	*	*	*	*
3	HOT	HOU	HPG	HPT	HPU	HQU	IJU	ILM	ILN	ILO	ILP	ILQ	ILT	ILU	IMO	IMP	IMT	IMU	INP
	*	*		*	*	*	*	*	*	*	*	*		*	*	*	*	*	*
3	INU	IOP	IOQ	IOR	IOU	IPQ	IPR	IPT	IPU	LMN	LMO	LMP	LMQ	LMT	LMU	LNP	LNU	LOP	LOT
	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
3	LOU	LPR	LPU	LQT	LQU	MNP	MNT	MNU	MOP	MOT	MPQ	MPT	MPU	MQT	MQU	NOP	NOT	NPT	NPU
	*	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
3	OPR	OPT	OPU																
	*	*	*																

MANUFACTURER NO. 4
17 PACKS 76 CELLS

4	ABD	ABP	ABQ	ABT	ACE	ACP	ACQ	ACT	ADL	ADQ	ADT	AEF	AEP	AEQ	AEG	AET	AFP	AFT	AGL
												*			*	*			*
4	AGP	AGQ	AGT	AIT	ALT	ANP	ANQ	APQ	APT	BCG	BDE	BDG	BDI	BDL	BDP	BDQ	BDT	BDU	BEF
	*	*	*			*	*					*							
4	BEP	BEQ	BET	BEU	BGL	BGP	BGQ	BGT	BGU	BIT	BLT	BOP	CDG	CDQ	CDP	CEF	CEG	CEP	CEQ
					*	*	*		*				*				*	*	
4	CET	CEU	CFG	CGI	CGL	CGP	CGQ	CGT	CNP	CNQ	CPQ	DEG	DEP	DEQ	DFG	DFP	DGL	DGQ	DGT
					*	*	*			*		*	*		*	*	*	*	*
4	DGU	DIL	DLT	DPQ	DPU	DQU	DTU	EFL	EFP	EFU	EGQ	EIT	EPQ	EPT	EPU	EQT	EQU	FGT	FNP
	*				*	*	*		*	*	*	*	*		*	*	*		
4	FNQ	GIL	GIT	GLT	GPQ	GTU	NPQ												
	*	*	*	*	*	*	*												

TABLE E-3

APPENDIX A

"BIGRAM" TABLES

"BIGRAM" TABLES

This section is presented for background and reference value only.

The Crane Test Program goes beyond simple life testing where only cycle of failure is recorded. As cells fail during cycling they are removed from the pack which is continued on cycling if three cells in a five pack or five cells in a ten pack remain. All removed, failed cells are opened and a post-mortem examination is performed. Results of such examination are included in the "Monthly Progress Report on National Aeronautics and Space Administration Space Cell Test Program" with complete cell and pack identification. The examination results are reported in descriptive English, such as the following report for pack 15, Cell 4: "Low Voltage Discharge, Low Voltage Charge, Migration of Negative Plate Material through Separator, Hot Spots Around Pinpoint Penetration, Blistering on Positive Plate, Separator Deteriorated".

A simple, experimental code structure of failure characteristics, as defined by Crane, was devised. Table A, page 11 shows the code legend. Table B, page 12 is a tabular presentation of the failure characteristic information provided in the Crane post-mortem reports. Columns are cell numbers, while row headings contain pack numbers and the manufacturer's code number. Table B is included for reference value only.

A computer was programmed to examine the coded failure characteristic data and to produce as output "BIGRAM" tables showing frequency of failure by one characteristic jointly with each of the other failure characteristics. Table V, page 40 shows joint frequencies for Manufacturers 1, 2, 3, and 4. Tables W, X, Y, and Z show the joint frequencies by individual manufacturers. The tables may best be read by

"BIGRAM" TABLES (Cont'd)

arranging the code letters of the desired couplet of failure characteristics in alphabetical order and then finding the intersection of the column headed by the first letter with the row headed by the second letter. Thus, in Table V, the total frequency of the joint failure characteristics of "B" and "N" for the four manufacturers is 7. The use of the computer in constructing these "BIGRAM" tables was invaluable. The computer accomplished in minutes correct tables that would have consumed many hours of error producing hand work.

The circled numbers in Tables X, Y, and Z indicate that cells made by the subject manufacturer accounted for all the indicated joint characteristics of failure. It can be observed that certain failure characteristics are totally accounted for by cells made by a given manufacturer. A more complete analysis would indicate those occasions where a majority of joint failure characteristics were accounted for by a given manufacturer's cells. This is illustrated by the numbers with dotted circles in Table Z.

With this technique, valuable information not available with other means can be gained. A computer program, now in the writing, will construct "TRIGRAM" tables. The "TRIGRAM" tables will show the frequency of any three failure characteristics jointly with each other.

Effort will be made to determine correlations, if any, between cycling parameters and failure characteristics.

MANUFACTURER #1, 2, 3, 4

92 Packs

361 Cells

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
A																					
B	130																				
C	91	166																			
D	32	47	35																		
E	24	31	27	4																	
F	42	92	100	11	8																
G	3	6	9	4	1	2															
H	10	32	35	2	0	27	1														
I	42	77	56	9	9	31	3	13													
J	0	1	2	0	1	0	0	1	1												
K	8	25	23	6	1	16	0	5	0	0											
L	50	88	68	20	6	40	3	13	39	2	5										
M	8	17	7	2	1	6	0	8	8	0	0	9									
N	1	7	4	1	0	2	1	3	2	0	0	6	4								
O	34	58	16	1	5	7	1	6	26	0	0	19	5	1							
P	41	86	49	13	14	28	1	8	19	0	2	32	11	9	13						
Q	31	64	63	16	11	31	2	7	5	0	14	12	2	1	2	30					
R	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	2	0				
S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
T	27	51	72	23	4	31	8	16	19	0	13	44	9	3	4	18	22	0	0		
U	0	63	24	5	5	14	1	6	12	1	3	20	3	5	10	31	19	0	0	12	

TABLE V

MANUFACTURER #1

15 Packs

66 Cells

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
A																					
B	17																				
C	17	45																			
D	3	6	7																		
E	4	5	8	1																	
F	8	24	27	1	2																
G	0	0	0	0	0	0															
H	2	10	12	0	0	7	0														
I	6	13	15	0	0	13	0	4													
J	0	0	0	0	0	0	0	0	0												
K	0	0	0	0	0	0	0	0	0	0											
L	2	5	12	0	0	6	0	0	2	0	0										
M	0	0	0	0	0	0	0	0	0	0	0	0									
N	0	0	0	0	0	0	0	0	0	0	0	0	0								
O	0	0	0	0	0	0	0	0	0	0	0	0	0	0							
P	0	6	5	1	0	2	0	0	0	0	0	0	0	0	0						
Q	2	14	13	0	2	5	0	1	0	0	0	0	0	0	0	5					
R	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
T	10	11	21	3	10	4	0	2	2	0	0	7	0	0	0	5	9	0	0		
U	0	12	8	0	0	2	0	1	2	0	0	0	0	0	0	4	9	0	0	8	

TABLE W

MANUFACTURER #2

11 Packs

47 Cells

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
A																					
B	13																				
C	11	33																			
D	5	9	9																		
E	1	3	1	1																	
F	5	19	14	2	1																
G	0	1	1	0	0	0															
H	1	5	4	1	0	4	0														
I	0	0	0	0	0	0	0	0													
J	0	0	0	0	0	0	0	0	0												
K	8	25	23	6	1	16	0	5	0	0											
L	0	8	8	3	1	5	0	0	0	0	5										
M	0	0	0	0	0	0	0	0	0	0	0	0									
N	0	0	0	0	0	0	0	0	0	0	0	0	0								
O	0	0	0	0	0	0	0	0	0	0	0	0	0	0							
P	1	5	5	3	0	2	0	1	0	0	2	2	0	0	0						
Q	6	17	17	8	2	7	0	3	0	0	14	5	0	0	0	2					
R	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
T	2	11	14	5	0	8	1	2	0	0	13	3	0	0	0	2	8	0	0		
U	0	4	3	0	0	1	0	0	0	0	3	0	0	0	0	1	1	0	0	3	

TABLE X

MANUFACTURER #3

49 Packs

172 Cells

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
A																					
B	56																				
C	26	52																			
D	5	9	8																		
E	5	7	2	0																	
F	13	36	41	5	0																
G	0	1	3	0	0	1															
H	6	15	18	1	0	15	1														
I	29	54	33	5	7	16	1	9													
J	0	1	2	0	1	0	0	1	1												
K	0	0	0	0	0	0	0	0	0	0											
L	24	50	34	5	4	21	0	12	28	2	0										
M	8	17	7	2	1	6	0	8	8	0	0	9									
N	0	7	3	1	0	1	1	3	2	0	0	6	4								
O	34	58	16	1	5	7	1	6	26	0	0	19	5	1							
P	14	49	16	2	2	17	0	7	19	0	0	25	11	8	13						
Q	4	15	17	0	0	16	0	2	4	0	0	6	2	0	2	5					
R	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	2	0				
S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
T	5	8	25	4	1	15	2	11	12	0	0	18	9	3	4	6	3	0	0		
U	0	38	9	2	2	10	0	5	10	1	0	20	3	5	10	22	5	0	0	0	

TABLE Y

MANUFACTURER #4

17 Packs

76 Cells

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
A																					
B	44																				
C	37	36																			
D	19	23	11																		
E	14	16	16	2																	
F	16	13	18	3	5																
G	3	4	5	4	1	1															
H	1	2	1	0	0	1	0														
I	7	10	8	4	2	2	2	0													
J	0	0	0	0	0	0	0	0	0												
K	0	0	0	0	0	0	0	0	0	0											
L	24	25	14	12	1	8	3	1	9	0	0										
M	0	0	0	0	0	0	0	0	0	0	0	0									
N	1	0	1	0	0	1	0	0	0	0	0	0	0								
O	0	0	0	0	0	0	0	0	0	0	0	0	0	0							
P	26	26	23	7	12	7	1	0	0	0	0	5	0	1	0						
Q	19	18	16	8	7	3	2	1	0	0	0	1	0	1	0	18					
R	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
T	19	21	12	11	2	4	5	1	5	0	0	16	0	0	0	5	2	0	0		
U	0	9	4	3	3	1	1	0	0	0	0	0	0	0	0	4	4	0	0	1	

TABLE Z